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The Simulation of a General Hospital Evacuation

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Abstract

In this paper, we compare and analyze the evacuation time required at a general hospital using an evacuation simulation program and propose an optimized procedure to improve safety. The paper analyzed the evacuation time of all occupants, including patients who cannot evacuate by themselves. The following four cases were analyzed in order: the width of evacuation stairs is 120cm, 130cm, 140cm, and 150cm. The results of the evacuation simulation showed that the total evacuation time is 1998s, 1796s, 1651s, and 1161s, respectively. For every 10cm increase in the width of the evacuation stairs, the evacuation time decreases by 202s, 145s, and 91s in sequence. The evacuation time decreases as the width of the evacuation stairs increases. However, the rate of reduction in evacuation time decreases. Therefore, simply increasing the width of evacuation stairs cannot significantly improve evacuation efficiency, and it is necessary to choose an appropriate width of evacuation stairs. In addition, all four cases simulations display that after 600 seconds, the evacuees are concentrated in two evacuation stairs, while there are very few evacuees in the other stairs. To solve this problem, it is necessary to disperse the movement route and consider multiple avoidance methods.

Key Words: *Pathfinder, evacuation safety, general hospitals*

1. INTRODUCTION

More than one thousand fires occur in global hospitals every year [1]. In particular, general hospitals generally have the characteristics of complex building space, high occupant density and large differences in occupant evacuation rates, which may cause significant casualties and serious economic losses in the event of emergencies. Therefore, the evacuation of general hospitals has increasingly received high attention from scholars and practitioners.

Due to the particularity of general hospitals, conducting evacuation experiment is not only dangerous, but also affects the normal operation of hospitals. Computer simulation has the advantages of safety, high

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efficiency and convenience, and establishing a rational evacuation model is an important means of studying hospital occupant evacuation. D'Orazio et al. (2020) simulated the evacuation of the inpatient ward on the third floor of the Campus Bio-Medico University Hospital of Rome in three different fire scenarios, using Pathfinder [2]. Tang et al. (2021) proposed an improved cellular automaton (CA) model to describe motion behaviors during the non-emergency evacuation in the hospital registration hall [3]. Tinaburri (2022) also adopted Pathfinder to simulate the evacuation of a two-story inpatient ward building [4]. Sahebi et al. (2022) predicted the real emergency evacuation duration of 190 patients following hospital fire using machine-learning algorithms [5]. Boonngam and Patvichaichod (2020) simulated fire evacuation of a 10-story hospital building with Pathfinder in Thailand [6].

In the evacuation simulation of hospital buildings mentioned above, although the walking speeds of occupants during evacuation were taken into account, the situation that people with higher disability levels need corresponding auxiliary tools for evacuation was ignored in the actual evacuation process, and the use of wheelchairs and mobile beds were not considered. There are certain limitations for the study of occupant evacuation in general hospitals.

In this paper, considering the occupants with different disability levels, Pathfinder is used to visually simulate and analyze the evacuation scenarios of general hospitals, which can provide reference for emergency safety design of general hospitals.

2. MODEL BUILDINGS AND CALCULATIONS

2.1. The Software

Pathfinder is a simulation program developed by Thunderhead Engineering Company in the United States. It consists of three modules: a graphical user interface, the simulator, and a 3D results viewer. Pathfinder provides two primary options for occupant motion: an SFPE mode and a steering mode. The SFPE mode implements the concepts in the SFPE Handbook of Fire Protection Engineering [Nelson and Mowrer, 2002]. This is a flow model, where walking speeds are determined by occupant density within each room and flow through doors is controlled by door width. The steering mode is based on the idea of inverse steering behaviors. Steering behaviors were first presented in Craig Reynolds' paper "Steering Behaviors for Autonomous Characters" [Reynolds, 1999] and later refined into inverse steering behaviors in a paper by Heni Ben Amor [Amor et. al., 2006]. Pathfinder's steering mode allows more complex behaviors to naturally emerge as a by-product of the movement algorithms-eliminating the need for explicit door queues and density calculations.

The steering mode has been selected in this paper. By setting occupant parameters, the escape path of occupants can be displayed, and the behavior of occupants can respond to changes in the environment [7]. According to the special situation of hospital buildings, the evacuation of general hospitals can be simulated well through the setting of special components such as wheelchair, hospital bed and assistance evacuation team.

2.2. Introduction to the Target Hospital

Located in Dandong City, China, the hospital is currently under construction and is expected to officially open in 2024. The pediatrics and emergency departments are on the first floor of the hospital, as shown in Figure 1; the otolaryngology, ophthalmology, and internal medicine departments are on the second floor; the obstetric department and gynecology are on the third floor; the dermatological department is on the fourth floor; the department of stomatology is on the fifth floor. The total construction area of the hospital is about 20000m^2; the length from east to west is 137m; the width from north to south is about 81m. The turnover of the hospital is large, with a maximum of 5000 people a day, which has strong research significance.

The CAD plan of the hospital was simplified and imported into Pathfinder to build the model. Figure 2 shows the Pathfinder model of the first floor. The seats, beds and others in the waiting hall and infusion hall of the hospital will occupy evacuation space, which may lead to the blockage of the evacuation path and reduce the evacuation speed of occupants. According to the arrangement law of the current objects in the halls, obstacles are set in the evacuation model to simulate the real circumstances.

Figure 1. Plan View of the First Floor

Figure 2. Pathfinder Picture of the First Floor

2.3. The Distribution of Occupants

Table 1 shows the distribution of the occupants in the building, which is determined by the Chinese standard, Code for Architectural Design of General Hospitals GB 51039-2014, and reference [8].

Table 1. The Arrangement of Occupants in the Hospital

Environment type	area (m^2)	Number of occupants		Environment type	area (m^2)	Number of occupants	
corridor	3300	925	elderly male: 315 elderly female: 305 adult male: 90 adult female: 85 children: 70 wheelchair user: 20 crutch user: 20 mobile bed user: 20	Infusion hall, first aid hall, emergency hall	4500	1125	elderly male: 400 elderly female: 410 adult male: 85 adult female: 80 children: 80 wheelchair user: 10 crutch user: 10 mobile bed user: 50
waiting rooms, waiting hall	4500	1280	elderly male: 455 elderly female: 450 adult male: 100 adult female: 95 children: 95 wheelchair user: 35 crutch user: 30 mobile bed user: 20	wards	4000	1050	elderly male: 245 elderly female: 235 adult male: 170 adult female: 160 children: 110 wheelchair user: 10 crutch user: 10 mobile bed user: 110
consulting rooms	1000	245	elderly male: 85 elderly female: 83 adult male: 20 adult female: 18 children: 20 wheelchair user: 9 crutch user: 8 mobile bed user: 2	offices and rest rooms for doctors and nurses	500	200	elderly male: 180 elderly female: 220 adult male: 0 adult female: 0 children: 0 wheelchair user: 0 crutch user: 0 mobile bed user: 0
operating rooms	500	100	elderly male: 34 elderly female: 32 adult male: 9 adult female: 7 children: 8 wheelchair user: 0 crutch user: 0 mobile bed user: 10	Rest room for other hospital staff	300	80	elderly male: 45 elderly female: 35 adult male: 0 adult female: 0 children: 0 wheelchair user: 0 crutch user: 0 mobile bed user: 0

2.4. Scenario Design

Table 2 shows four scenarios which are selected for this simulation, considering the width of evacuation stairs.

Table 2. Scenario

Scenario	Condition
Scenario 1	The width of evacuation stairs is 120cm.
Scenario 2	The width of evacuation stairs is 130cm.

Scenario 3	The width of evacuation stairs is 140cm.
Scenario 4	The width of evacuation stairs is 150cm.

Medical staff and patient families have the ability to walk and evacuate normally, but their evacuation ability varies significantly depending on gender and age. Patients in hospitals, especially those who do not have the ability to walk (such as being paralyzed in bed, etc.), need to use wheelchairs or mobile beds with the assistance of others for outdoor activities and emergency evacuation. The process of emergency evacuation of occupants with different walking speeds is often more complicated than that of ordinary occupants, and the evacuation efficiency will be reduced. Therefore, the evacuation speed of occupants should be set separately. In this paper, parameters of evacuees are set based on reference [7], as shown in Table 3.

Table 3. Input to Simulation

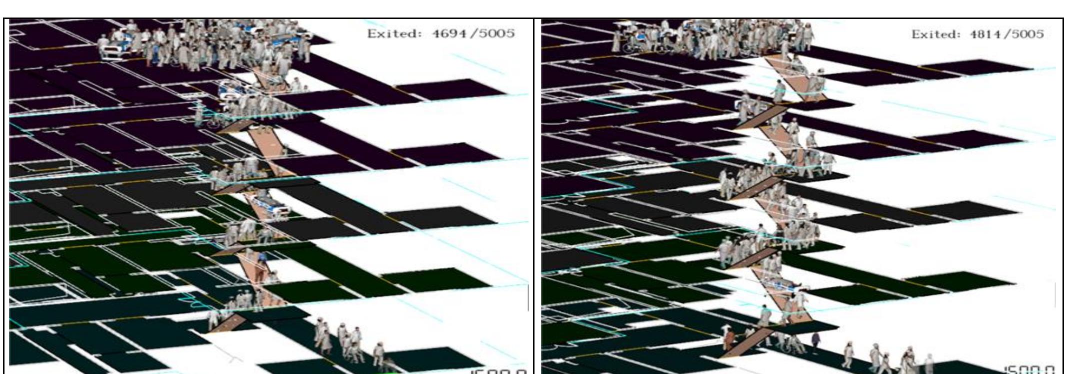
Profile	elderly male	elderly female	adult male	adult female	children	wheelchair user	crutch user	mobile bed user
speed (m/s)	1.15	1	0.85	0.8	0.75	0.65	0.5	0.5
shoulder width (m)	0.5	0.4	0.53	0.46	0.33	0.7	0.6	0.9
reduce factor	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
response time (s)	1.6	1.6	2	2	1.6	2.2	2.2	2.5
Personal distancing(m)	0.08	0.08	0.08	0.08	0.07	0.1	0.1	0.1
collision reaction time (s)	1	1	1	1	1	1.5	1.5	1.5
preparation time（s）	10	20	40	40	20	20	20	120

3. SIMULATION RESULT AND ANALYSIS

3.1. Simulation Result

The evacuation simulation of four scenarios is carried out by Pathfinder, and the evacuation time is 1998s, 1796s, 1651s and 1161s, respectively. Figure 3 shows the evacuation scenes of the same evacuation location, the same evacuation time in four scenarios.

According to the simulation results, the evacuation time decreases with the increase of the width of the evacuation stairs. But the rate of reduction of evacuation time decreases. The width of the evacuation stairs is increased from 120cm to 130cm, and the evacuation time is reduced by 202s; the width of the evacuation stairs is increased from 130cm to 140cm, and the evacuation time is reduced by 145s; the width of the evacuation staircase is increased from 140cm to 150cm, and the evacuation time is reduced by 91s.



Scenario 1 **Scenario 2**

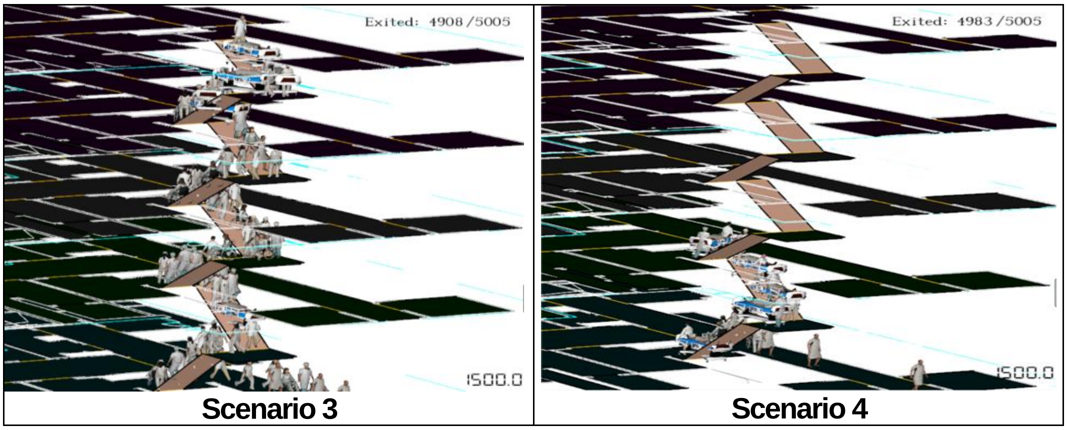


Figure 3. Evacuation Scenes at 1500s

Figure 4 shows the curves which describe relationship of evacuation time and number of evacuees. The trend of these curves is nearly the same in four scenarios. The number of evacuees increases over time, but the trend shows a phased change. From 50 s to 110s, the change of the number of evacuees over time is obvious, and the evacuation efficiency is high. With the increasing number of occupants on the first floor, the evacuation efficiency decreases. After 600s, the evacuees on the second floor and above mainly gather in the evacuation stairs, which greatly reduces the evacuation efficiency. As shown in Figure 5, after about 600s, the evacuation scenes show that the evacuees mainly gather in the two evacuation stairs, while there are very few evacuees in other stairs.

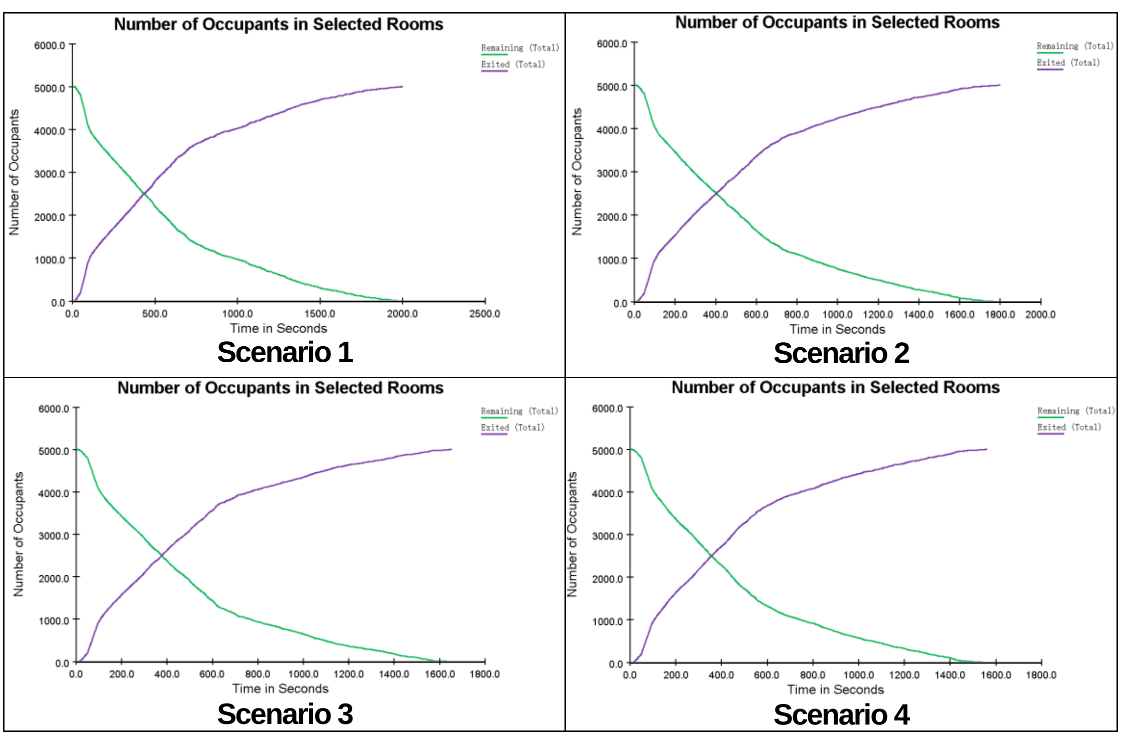


Figure 4. The Relationship Curves between Evacuation Time and Number of Evacuees

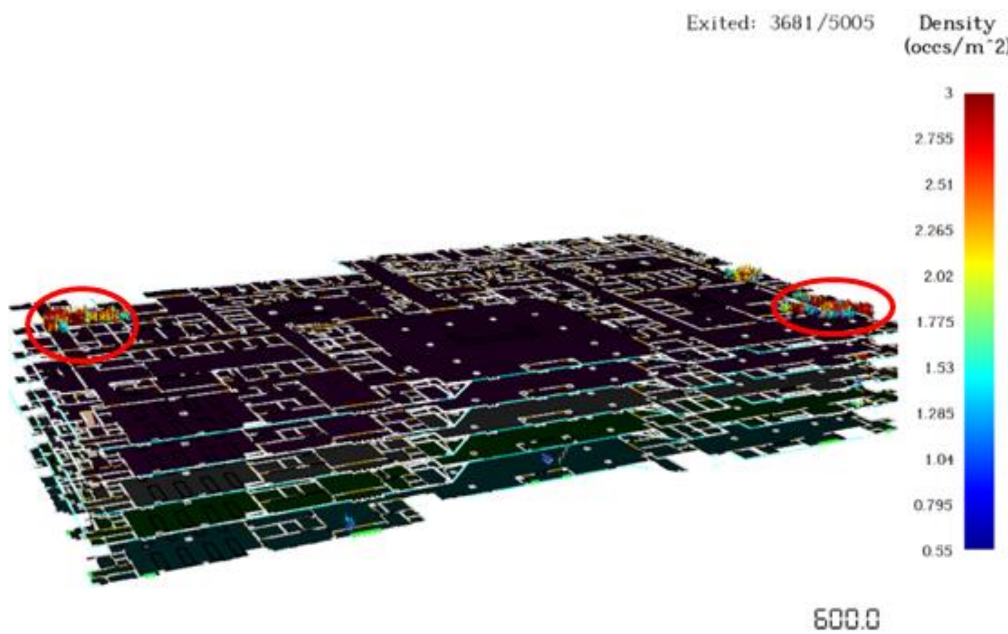


Figure 5. Evacuation Scenes at 600s

3.2. Analysis of Simulation Result

1. Choose the rational width of stairs

The width of the stairs is too large, which not only causes the increase of cost, but also results in less significant improvement in evacuation efficiency. Therefore, under the premise of meeting the evacuation requirements, rational wide stairs should be used instead of excessively wide stairs.

2. Dispersion of evacuation paths

As the number of evacuees increases, bottleneck phenomena may occur, and all evacuees are unable to move normally, which can easily lead to large-scale accidents. In order to solve this problem, it is necessary to disperse the evacuation paths. Thus, multiple evacuation methods can be used.

4. CONCLUSION

In the paper, the safety evacuation is simulated in a general hospital. Based on the width of evacuation stairs, four scenarios are designed. The evacuation time decreases with the increase of the width of the evacuation stairs, while the rate of reduction of evacuation time decreases. Therefore, it is necessary to choose the appropriate width rather than the maximum width to design evacuation stairs design. In addition, through the analysis of the relationship between the evacuation time and the number of evacuees, other evacuation methods can be considered to improve the evacuation efficiency.

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